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AN INDEX OF PACK-ICE SEVERITY OFF NEWFOUNDLAND AND ITS SECULAR VARIATION

By M. K. MILES

Summary. From the available observations of the edge of pack ice off Newfoundland an index has been formed for each year since 1920. This index is an attempt to represent the area of maximum extent, usually reached in April. The decadal means of this index show a slow decrease in the frequency of severe occurrences up to 1950 with a rapid fall to zero in the decade 1961–70.

There is a clear connection between the decadal means and the strength of north-westerly flow off the coast of Labrador. The greatly reduced amount of pack ice in the last two decades can in part be attributed to the reduction in the vigour of the North Atlantic winter circulation, but there is an indication of a lag of some 20 years which may indicate that the strength and temperature of the Labrador current is an important controlling factor.

Introduction. April is the month in which pack ice usually reaches its greatest eastward and southward extent near and over the Grand Banks off Newfoundland. The additional sea area covered with ice in a severe season compared with a light season is comparable to that of the United Kingdom, and represents a volume of ice at least 10 times as great as that carried into the Atlantic as icebergs in a heavy year. It therefore seems worth while to have an index related to this area for as many years as possible. The following data sources were used in forming an index:

(a) Maps of the edge of the 'field ice' for 1920–39 held in the Meteorological Office.

(b) Profiles of the edge of the 'field ice' for 1946–55 given by Tunnell.[1]

(c) United States Coast Guard bulletins and ice maps prepared by the Meteorological Office.

Formation of index. The relation of the maximum eastward and southward extent of the ice in April with an index of icebergs off Newfoundland as given by Groissmayer[2] and Corkum[3] was examined separately, and it was concluded that an index formed by adding the longitude and latitude of these would be a reasonable indicator of the ice situation. The greatest eastward extent was to 45°W in 1921 and the least was to 53°W in 1970. The greatest southward extent was to $42\frac{1}{2}$°N in 1921 and the least to 51°N in 1971. Thus the index for 1921 comes to $87\frac{1}{2}$ and indicates the most severe occurrence in the period while the index of $102\frac{1}{2}$ for 1971 represents the lightest occurrence.

The annual indexes for the period 1920–73 are given in Table I. There is not enough information to form an index for the years 1940–42 (inclusive) but they are described in the United States Coast Guard bulletins as being all three very light ice years.

TABLE I — INDEXES OF PACK ICE OFF NEWFOUNDLAND IN APRIL

	0	1	2	3	4	5	6	7	8	9
192–	91	87½	91	90	99	97	90	91½	96	89½
193–	96	100	91½	93	91½	89½	95	96½	92½	90
194–	—	—	—	95	92	92	91	95½	94	97½
195–	90½	98	98	94½	93	93	95½	91	100	95½
196–	96½	97	98	98	99	99½	102	98	102	102
197–	102	102½	98	92½						

Low values indicate severe ice, high values light ice.

The absolute values of such an index cannot be a completely accurate measure of the extent of the pack ice in any one season for several reasons:

(a) Errors in determining the edge of open pack ice (about five-tenths cover).

(b) Differing shapes of the ice edge.

(c) Extremes sometimes occurring in late March and even in May.

However, they should give a fairly reliable indication of whether the pack ice was heavy, moderate or light in individual years, and the decadal means should reveal any strong secular trend that there may be.

The 51 values have been divided into three nearly equal groups with the following tercile boundaries:

Tercile 1 (light ice) ≥ 98;

Tercile 2 (moderate ice) <98 and ≥ 93;

Tercile 3 (heavy ice) <93.

Secular variation of the index. The distribution of light, moderate and heavy years in the successive decades together with decadal means of the index are given in Table II. From the average values of the index, and from the frequency of severe occurrences, it is clear there has been a reduction in the amount of pack ice over the Grand Banks during the period. The reduction was quite slow until the late 1940s, and was very marked from the late 1950s.

TABLE II — DECADAL MEANS OF PACK-ICE INDEX OFF NEWFOUNDLAND AND NUMBERS OF HEAVY, MODERATE AND LIGHT YEARS

Decade	Mean index	Number of years			
		Heavy	Moderate	Light	
1921–30	92·7	7	2	1	
1931–40	93·3 (9 years only)	5	3	1	(or 2 if 1940 taken as light)
1941–50	93·4 (8 years only)	4	4	0	(or 2 if 1941 and '42 taken as light)
1951–60	95·5	2	5	3	
1961–70	99·7	0	2	8	

It is interesting to compare this change with other known climatic trends during this period. Schell[4] has shown that the number of icebergs counted each year south of 48°N off Newfoundland is related to the strength of the north-westerly winds off Labrador during December to March, so it is reasonable to think that the latter may also be related to the amount of pack ice. The index used here for the strength of the north-westerlies is the average

pressure difference between 50°N 60°W and 60°N 50°W for the months December, January and February. The decadal averages of this pressure difference are shown in Figure 1 which also contains the decadal means of the pack-ice indexes.

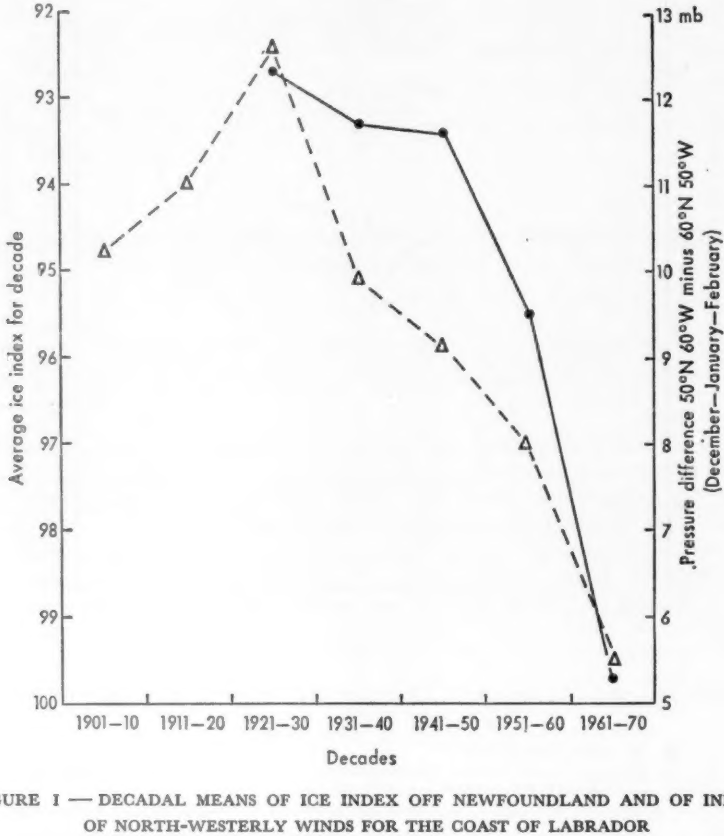

FIGURE 1 — DECADAL MEANS OF ICE INDEX OFF NEWFOUNDLAND AND OF INDEX OF NORTH-WESTERLY WINDS FOR THE COAST OF LABRADOR

●——● Ice index off Newfoundland.
△ - - - △ Index of north-westerly winds for coast of Labrador.

The reduction in the amount of pack ice is clearly related to the reduction in the strength of the north-westerly winds, which is a reflection of the well-known decrease in the average intensity of the Iceland low during the months of December, January and February over the period 1930–70. There is, however, a distinct hint of a lag in the reduction of ice behind the decline in the north-westerly flow. This hint is confirmed when note is taken of the secular change of air temperatures at stations on the west coast of Greenland. The decadal means of the average winter temperature for Jakobshavn (69°N 51°W) and Godthaab (64°N 52°W) are given in Figure 2 together with the ice indexes, and show a steep rise in the 1920s with maintained higher values in the decades

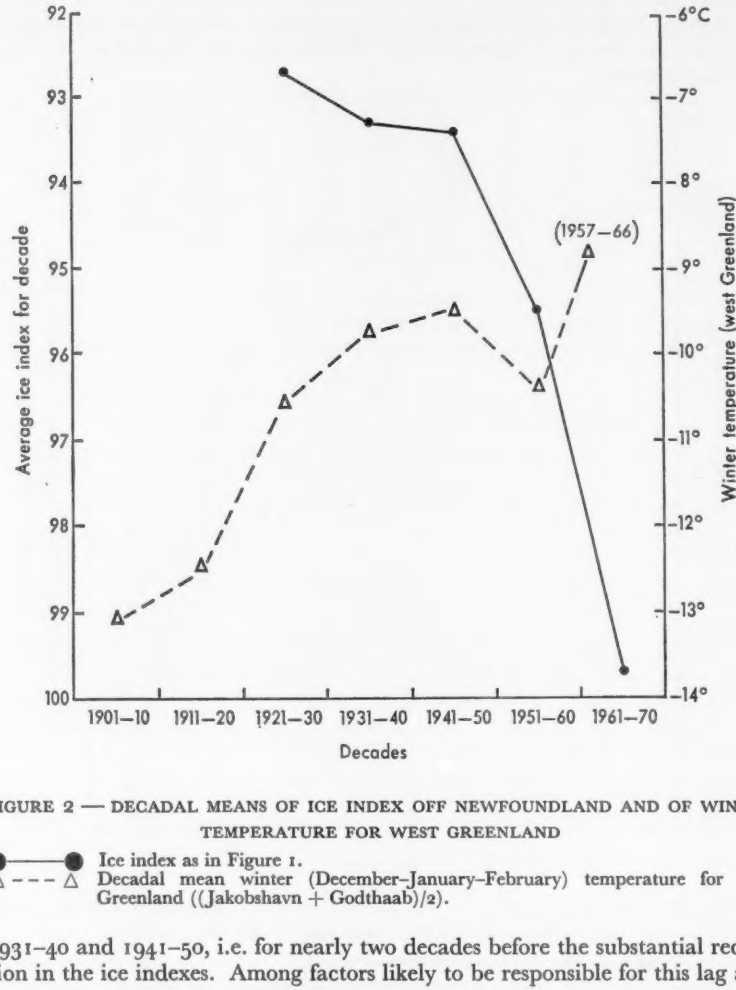

FIGURE 2 — DECADAL MEANS OF ICE INDEX OFF NEWFOUNDLAND AND OF WINTER TEMPERATURE FOR WEST GREENLAND

●——● Ice index as in Figure 1.
△ – – – △ Decadal mean winter (December–January–February) temperature for west Greenland ((Jakobshavn + Godthaab)/2).

1931–40 and 1941–50, i.e. for nearly two decades before the substantial reduction in the ice indexes. Among factors likely to be responsible for this lag are:

(a) a lag in the warming of the source regions of air brought down the Labrador coast in winter compared with the warming in east Greenland,

(b) a secular change in the strength and/or temperature of the Labrador current, and

(c) a secular change in the average northern limit of the Gulf Stream south of Newfoundland in the late winter and early spring.

The examination of these factors, should the available data be adequate, may provide some insight into the time scale of interrelated processes bound up with the North Atlantic winter circulation.

Finally, it is worth noting that the increased amounts of ice reported in this

area in the springs of 1972 and 1973 (in 1972 mainly off Labrador, hence the not very high value of the index) were accompanied by values of the north-westerly index typical of the 1920s and 1930s.

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THE USE OF WEATHER-RADAR DATA IN COMMUNICATION ENGINEERING*

By T. W. HARROLD

Summary. Precipitation particles attenuate radio signals above a frequency of about 10 GHz. In planning communication links statistical information concerning the attenuation is required. In this review current methods of obtaining this information, including the use of weather radar, are summarized.

Communication problems caused by precipitation. The use of microwave frequency bands for communication links is such that the communication engineer is compelled to use increasingly high frequencies in order to find an available band. The reliability of links above about 10 GHz (3-cm wavelength) is significantly influenced by attenuation (fading) due to precipitation particles. The attenuation per unit distance at a given rate of rainfall increases with frequency, so the importance of attenuation will increase as the higher frequencies are exploited. A further problem is that the scattering (as opposed to attenuation) of radio energy by precipitation at frequencies shared by terrestrial and satellite communication systems is a significant source of potential mutual interference in these systems. The problems are such that the occurrence of precipitation will be a decisive factor in the design and operation of future communication links.

Methods of solution. One method of improving the reliability of a high-frequency communication system is to design the system with the distance between repeater stations sufficiently small that the probability of significant attenuation is reduced to an acceptable level, say a few seconds per year. This entails knowing the probability of attenuation along the path. Another means of improving the reliability is to use the concept of space (path) diversity. For terrestrial links this entails having two or more paths between terminals, positioned so that the probability of both paths being affected by significant attenuation at the same time is at an acceptable value. For earth–space links more than one receiving station has to be employed. The planning of a diversity system thus requires statistics of the mesoscale distribution of precipitation.

*A review based on relevant discussions at the Inter-Union Commission for Radio Meteorology Colloquium on the Fine Scale Structure of Precipitation and Electromagnetic Propagation which was held at Nice, France, on 23–31 October 1973.

It is also possible that the operation of a communication link would be improved if warning of an 'outage' arising from heavy precipitation could be given.

Techniques for obtaining attenuation data

(a) *Direct measurements.* The most direct, but not necessarily the most satisfactory, approach is to measure the attenuation. Existing methods of obtaining data relevant to the planning of earth–space links are:

(i) Use of transmissions from satellites. A signal dynamic range of about 40 dB and a moderate amount of data can be obtained but a major disadvantage is cost; costs are less for smaller dynamic ranges.

(ii) Use of the sun as a microwave source. The usable signal dynamic range is 25–30 dB but only a small amount of data can be obtained. The cost of the receiving equipment is about £25 000.

(iii) Use of sky emission radiation. A larger amount of data can be obtained and the equipment cost is smaller, about £17 000, but the usable dynamic range is only about 10 dB.

These methods do not provide any information concerning suitable locations of the paths in a diversity system unless more than one receiving station is used.

For terrestrial links the only method of obtaining attenuation measurements directly is to use an existing link or establish a new one. In order to study a diversity system several links are required.

Only a limited amount of data can be gathered by these methods and careful interpretation is required if conclusions from these data are applied to other localities or in planning future systems.

(b) *Use of rain-gauge data.* The most practical, inexpensive and widely used method of obtaining attenuation statistics is by the indirect means of using existing surface rain-gauge data. Rate of rainfall (R) is related to the attenuation (A) by an empirical expression of the form $A = C.R^d$, where the constants C, d depend on the drop-size distribution of the rain. The advantage of the method is that rainfall data are available from many parts of the world and for sufficiently long periods of time. (In planning a link, which has a lifetime typically of 20 years, it has been found that statistics derived over the previous 15 years are more representative of the period than longer-term statistics.) Difficulties in deriving attenuation statistics from rain-gauge data are that:

(i) The statistics are required over periods of a minute or less; they generally have to be derived from rainfall records with a coarser time resolution so that errors are introduced, particularly for high rates of rainfall.

(ii) Statistics along a line are required, so some spatial model of the precipitation has to be applied to the point data from the rain-gauges and this introduces further errors.

(iii) The attenuation along a line above the surface of the earth is derived from a relationship between rate of rainfall and attenuation. There is a theoretical basis for this relationship in the absence of vertical air motion, but this condition is unlikely to be met in many of the short-period heavier rates of rainfall of interest to the communication engineer so additional errors in the predicted attenuation will be introduced.

A development of the use of rain-gauge data has been the establishment of lines of short time resolution rate-of-rainfall recorders to measure line rainfall directly. This minimizes errors (i) and (ii) above and also permits an improved model relating point to line rainfall to be developed which can be applied to other point-rainfall data in the same locality. However, error (iii) is still present. A further disadvantage is that the setting up and particularly the running of a number of rainfall recorders is costly. For example, the running of and processing of data from a network of 60 magnetic-tape rain-gauges in North Wales costs over £30 000 per annum.

(c) *Use of disdrometer data.* A disdrometer measures the drop sizes of the rainfall. With this knowledge the attenuation can be computed directly, rather than by using an empirical relationship as in (b). This is therefore a more accurate means of estimating attenuation but has the disadvantage that the data required are only available for short periods and from a few locations.

(d) *Use of weather-radar data.* An alternative to either direct measurement or indirect estimates from rain-gauge data which is being used increasingly in deriving attenuation statistics is the use of quantitative data from a weather radar. The attenuation (A) is estimated from measurements of the radar reflectivity factor (Z) by using an empirical relationship of the form $A = E.Z^f$, where E and f are constants related to the raindrop size distribution. By comparing attenuations estimated in this manner with simultaneous direct measurements using a satellite, Strickland[1] showed that the standard error in the radar-derived estimates was less than 0·3 dB for 1 dB of attenuation, increasing to about 0·75 dB ($\approx$ 18 per cent) at 8 dB of attenuation. Advantages of this method over the use of rain-gauges are:

(i) A large area (about 10^4 km^2) is observed from a single installation. Many links can be simulated within this area so that a large data sample can be obtained in a short period.* The extensive coverage is also an advantage when planning a diversity system because the mesoscale distribution of attenuation as well as line statistics are then required. These can be derived from networks of rate-of-rainfall recorders, but such networks are expensive to establish and maintain and the uncertainties in estimating attenuation from rainfall data remain. It is simpler to use weather-radar data in deriving the mesoscale information. For example, it is now well known from such data that precipitation on the mesoscale is often banded; any preferred orientation or locality of these bands in a particular region would be very significant factors in the siting of communication links.

(ii) Attenuation and radar reflectivity both depend on the volume concentration of drops, whereas rate of rainfall is a flux which depends also on the vertical air motion. Attenuation calculated from a surface rate of rainfall will not be the same as that aloft if there is vertical air motion. As a simple illustration, consider a volume concentration of N drops/cm^3

* *Note.* The simulation of a number of links is not necessarily equivalent to obtaining a number of years' data over one link because meteorological conditions during the limited time sample may not be representative of the longer period. An example of this is provided by the summer of 1973 in England. Weather-radar data would have permitted statistics of attenuation in an extreme weather type—heavy thunderstorms—to be obtained which might have taken centuries to obtain by using one experimental link and as such might have been valuable; however, the data sample would not have been representative of more typical seasons.

all of the same size and with a still-air fall velocity of 5 m/s falling into a rain-gauge. If at a higher level the drops were within a downdraught of 2 m/s, the volume concentration would be 5 $N/7$ drops/cm^3 (excluding a small effect due to the horizontal divergence of the flow) and the attenuation would be only 71 per cent of that estimated from the surface data. The magnitude of the error arising from using surface rain-gauge data can therefore exceed that in the radar method.[1]

Disadvantages of using weather radar to obtain the required data are:

(i) The cost of a suitable weather-radar station, which is between £50 000 and £100 000. This is prohibitive compared with the costs of using existing rain-gauge data or a direct measurement system, but it may be comparable to the cost of a rain-gauge network developed for the specific purpose of measuring attenuation.

(ii) The radar beam, which is usually between 0·5° and 2° wide, is an order of magnitude larger than the beam along a communication path, so that the rainfalls may not be the same. This restricts the value of the radar data in estimating path attenuation, especially beyond a range of about 50 km. Further, at times the radar beam may extend in height to the melting layer, in which case the echo intensity cannot be related to attenuation as accurately as when the beam is entirely within rain. This is also the case when hail is present within the beam. (In this circumstance a rain-gauge may also provide an erroneous measurement.)

In those parts of the world where radar data do not exist, planning must at this stage be based largely on interpretation of rainfall records. However, quantitative weather-radar data are becoming increasingly available in various parts of the world for meteorological and hydrological applications. Where such data do exist it seems preferable to use them to derive attenuation statistics along a line rather than rain-gauges, which provide a less accurate estimate, or direct measurements, the equipment for which is less readily available. In regions where additional information is required radar may well be the most effective means of obtaining it.

The present and possible future situation in the United Kingdom. Attenuation statistics in the United Kingdom are derived from routinely available rate of rainfall records in the manner described — see, for example, several papers by Briggs in the *Meteorological Magazine*.[2–4] The problem of relating point to line rainfall rates has been investigated by using data from the Cardington[5] and Winchcombe rain-gauge networks. In addition, communication engineers have established their own lines of rain-gauges near Mendlesham, Suffolk, where there are some 40 gauges along 8- and 16-km lines,[6] and Ilkley Moor, Yorkshire, where there are 10 gauges along a 13-km path.[7] Marine radars operating at a wavelength of 3 cm are used to interpolate the rainfall field between these gauges. Both these lines consist of specially developed rain-gauges[8] which record 10-second rainfall totals.

Weather radars have been used for a number of years by the Meteorological Office but these do not provide quantitative data, nor is any permanent record kept. More recently a quantitative radar has been used regularly in North Wales for hydrometeorological research studies in the Dee Weather Radar Project.[9] Quantitative data are also obtained occasionally by the Meteorological Research Unit at the Royal Radar Establishment at Malvern and the

Department of Electrical Engineering at the University of Birmingham. Other radars exist at various establishments, including one at the USAF base at Alconbury, Hunts. Data from all of these radars would be of some value in communication applications, in particular in deriving an approximate climatology of mesoscale precipitation. However, none is fully adequate for deriving detailed attenuation statistics. The situation would change if proposals for a quantitative weather-radar network consisting of 12 radars covering the United Kingdom come to fruition.[10] This network would operate continuously and would provide qualitative coverage over the whole country and neighbouring sea areas, as an aid to forecasting precipitation, and quantitative coverage within about 75 km of each radar, to permit surface precipitation to be measured over areas of particular interest, for example, river catchments.

Conclusion. Several methods of estimating statistics of attenuation for communication links and diversity systems are in use. The most direct method is to make actual measurements but the data sample is limited and the equipment is seldom available. When a quantitative weather radar is available, attenuation statistics can be readily derived and a large data sample attained. In the absence of a quantitative radar system, use is made of data from existing or specially installed rain-gauges. This is the method adopted in the United Kingdom at present but the situation could change if quantitative radar data were available.

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551.508.53/4: 621.398

THE METEOROLOGICAL OFFICE Mk 5 WIND SYSTEM

By C. V. ELSE

Summary. Increasing requirements for large numbers of wind-direction and speed indicators at separated points on large airports, and for wind data suitable for further processing, have shown the existing Meteorological Office Mk 4 wind system to be inadequate under these conditions. Development was undertaken of a new wind system (Mk 5) designed to overcome these difficulties. The outputs of the new system are compatible with the telemetry required for longer data-transmission paths. The direction and speed values are scaled in a manner which makes them suitable for use with most data-processing systems. The number of display outlets is unlimited, and various ancillary devices are provided to produce the most commonly needed processed data, for example, wind components, mean values and gust detection. Sets of the new equipment have been installed at several places, including London/Heathrow Airport, where the system has been fully duplicated.

Introduction. In 1954, because of the limitations of the Dines pressure-tube anemometer in regard to remote and multiple displays, the Meteorological Office introduced electrical systems of wind measurement based on magslip-type transmissions for wind-direction information, and a.c. generators for wind speed. These systems have been adequate in the past when the number of displays required has been modest, when there has been little need for further processing of the basic wind data, and when the cable distances between the sensing heads and the displays have been relatively short. As a result of recent demands for an increase in the number of displays, for these displays to be at greater distances from the sensing heads and sometimes widely separated from each other, and for the facility to process the basic wind data in various ways at the display points, limitations of the existing systems have become increasingly obvious and unacceptable.

The limitation of 10 ohms for the maximum resistance of the cables between the sensor and the wind-speed displays results in the use of extremely heavy and expensive cable when runs of 3–5 km are involved. Further, when these long runs are used the cable capacitance becomes important also. The standard Mk 4 cup-generator anemometer has an effective inductance of about 0·75 henry. This value, coupled with the capacity of the maximum specified lengths of cable, creates resonance in the system at the higher generated a.c. frequencies, and is liable in extreme circumstances to cause errors at wind speeds of 80–140 kt of over 10 per cent. This phenomenon is inherent in the design of the system.

There is also a 40-ohm limitation on the cable connecting the magslips which form the transmission system for wind direction. Although cable capacitance is of little importance in this instance, the receiver magslips used in the direction indicators have a marked resonance at about 4 Hz, which is excited by any fluctuations in wind direction at this frequency. This results in momentary anomalous indications on the dial.

The way in which the wind information is transmitted from the sensing heads to the displays, whilst adequate for the type of installation for which the systems were originally designed, does not lend itself to the further processing of the basic data for the meteorologist or air traffic controller. Such processing has therefore had to be done by human intervention, with all the limitations which such intervention implies.

Design criteria for the new system. As a result of the limitations listed above, of indications of the forms in which wind data are likely to be required

in the future, and of estimates of the increase in the number of displays likely to be required from a single measuring point, development was undertaken in 1969 of a new electronic wind-measuring system which would use the existing sensors but would have the following characteristics:

(a) Compatibility with transmission of the data by telemetry, using either cable or radio links, over great distances (preferably unlimited).

(b) Facilities to provide an unlimited number of displays.

(c) Facilities for the generation of orthogonal wind components, with respect to any selected axes.

(d) Facilities for the independent processing of the data in various ways at any point in the system.

(e) Great reliability.

(f) Low power consumption.

(g) Facilities for setting up and checking the system for correct operation by reference to independent external electrical standards.

(h) Facilities for the use of modified or different wind sensors, particularly wind-speed sensors with lower starting speeds.

The result of this development is the Meteorological Office Mk 5 wind system, which has now been introduced at London/Heathrow Airport. Whilst initially developed for use at civil airports and military aerodromes, it also offers facilities of interest in other fields, including:

(a) The derivation of instantaneous or averaged values of wind speed and direction, or of cross-wind and along-wind components for any runway on a continuous basis.

(b) The possibility of light-weight battery-powered equipment, capable of being dropped by parachute to transmit wind information by radio link from a remote site, or of being set up there.

(c) The input of wind data, processed in any desired way, into a data-logger or directly into a computing system.

(d) The provision of wind data in a form suitable for automatic extraction of gusts, deviation from mean values, Fourier analysis (within the limitations of the sensors and encoding systems) and similar processes.

Description of the components of the system

Wind direction. In order to ensure homogeneity (for climatological purposes) with earlier data, the Mk 5 system is designed to operate with the sensors used in the older electrical systems. However, there is no reason why new sensors should not be used with the same, or other, transducers to give similar results. The wind-direction transducer is a 2-in synchronous-link magslip. In the present application (Figure 1) the three-phase stator winding is energized by a three-phase a.c. sinusoidal supply, which induces in the magslip's rotor winding a single-phase sinusoidal waveform whose phase varies through 360 degrees, relative to a reference phase, as the rotor makes one complete revolution. From this variation in phase is generated a variable-width pulse waveform, which is processed* to give an output varying from 0 to 10 volts as the direction of the wind vane changes.

* The width-modulated pulses are processed by smoothing after the application of a d.c. clamp.

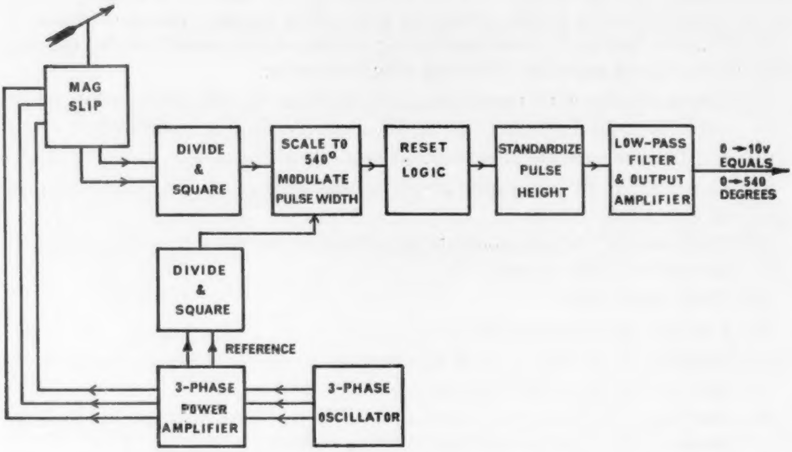

FIGURE 1 — BLOCK DIAGRAM OF WIND-DIRECTION ENCODING CIRCUITS

One of the major difficulties encountered in the design of telemetered wind-direction systems which use scales having fixed limits (as opposed to the circular compass-rose type of display which is continuous) is that, if the wind vane oscillates about the point corresponding to zero and full-scale output, the output is indeterminate since it varies rapidly between the two extremes. The wind-direction scale is therefore extended to cover a range of 0–540 degrees, and a small logic system is used to reset the scale deflexion from zero (or full scale) to a corresponding stable deflexion point at two-thirds (or one-third) of full scale respectively. Hence the scaling of the wind-direction indicator, shown in Plate I, is:

Direction (degrees)	090	180	270	360	090	180	270
a.c. signal (volts)	0·00	1·66	3·33	5·00	6·66	8·33	10·00

This scaling allows the 090-degrees (0-volt) deflexion to reset to the new stable position at 6·66 volts, and correspondingly permits the 270-degree (10-volt) deflexion to reset to 3·33 volts. It will be noted that the direction scale for this system starts at east and finishes at west. This is an arbitrary decision, since the scale could start at any convenient point. East was eventually chosen because it places north in the familiar position at top centre of the dial.

Wind speed. The wind-speed sensor is the standard Mk 4A three-cup anemometer, as in previous systems. This sensor is coupled to a transducer in the form of an a.c. generator. In the earlier systems, however, the output was the magnitude of the a.c. voltage produced by the generator, and this led to many problems. In order to obtain a sufficient output, a strong magnetic field was necessary and the resulting magnetic 'cogging' action led to a high starting speed (approximately 5 kt). In addition, the system was sensitive to the loading imposed by the displays, and this had to be kept constant by substituting

dummy loads. The number of displays was limited to six, and the system's accuracy was affected by the resistance and capacitance of the connecting cable between the generator and the displays. Because the a.c. voltage had to be rectified for use in the displays, the chart scale was also highly non-linear below about 10 kt, and this resulted in very poor resolution of wind speeds below this figure.

In the Mk 5 system the same generator is used, but the analogue of the required wind-speed information is now the frequency of the generated a.c voltage. This has freed the system from the previous restrictions. The resistance of the connecting cables ceases to be important. Furthermore, since the magnitude of the generated voltage is no longer of interest, the magnetic cogging action has been minimized by increasing the rotor–stator air gap. This has resulted in a lowering of the starting speed of the assembly to less than 2 kt. The chart scale is now substantially linear from starting speed upwards; this gives greatly enhanced resolution at low speeds.

The relationship between wind speed and rotational speed of the cup-generator anemometer is such that the output frequency increases by almost exactly one hertz per knot of wind speed. For each cycle of the generated frequency, two pulses of accurately known width and amplitude are produced in a conventional frequency-to-voltage converter (Figure 2). These pulses are

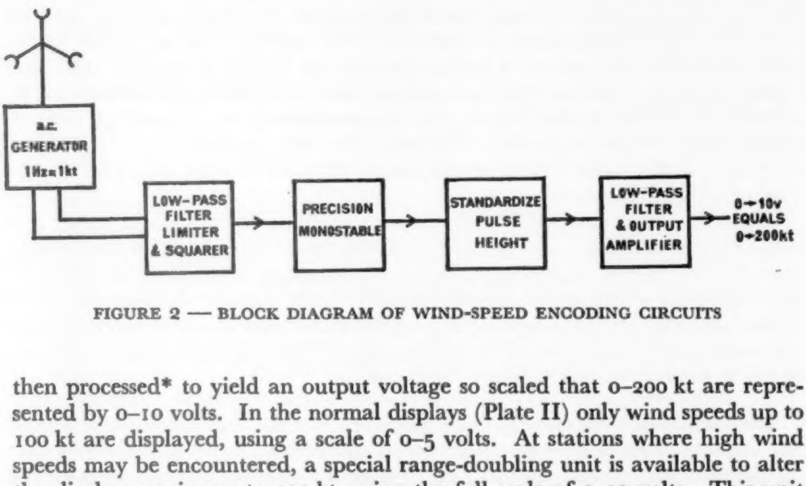

FIGURE 2 — BLOCK DIAGRAM OF WIND-SPEED ENCODING CIRCUITS

then processed* to yield an output voltage so scaled that 0–200 kt are represented by 0–10 volts. In the normal displays (Plate II) only wind speeds up to 100 kt are displayed, using a scale of 0–5 volts. At stations where high wind speeds may be encountered, a special range-doubling unit is available to alter the display maximum to 200 kt, using the full scale of 0–10 volts. This unit operates when the wind speed reaches a predetermined level in the range 70–90 kt. Once the scale-doubling action has occurred, it is locked in and a warning signal is displayed, resetting of the scale to the normal state being made manually as in the present Mk 4 system. Alteration of wind-speed scaling is effected locally, and need not apply to all indicators or recorders. The data being transmitted are *always* scaled on the basis that 0–10 volts represents 0–200 kt.

* The time-modulated pulses are processed by smoothing after the application of a d.c. clamp.

Display and telemetry. Any number of displays can be used, both locally and remotely. The data are displayed on suitably scaled conventional meters, or recorded on potentiometric or galvanometric recorders. A special servo-driven wind-direction indicator (Plate III) which converts the wind-direction information into the form of a 360-degree compass-rose display is available for locations (such as air traffic control centres) where the meter type of display is considered unsuitable. Electronic units at the outlet points are capable of supplying up to 50 displays of any type except galvanometric recorders. The high current requirement of these recorders limits the number which can be attached to a single electronic unit to 10. Figure 3 shows the schematic arrangement of the basic Mk 5 wind system on the sensor side of the telemetry link. Other display facilities can be specially arranged, and various forms of data processing are available. Some of the latter are available as standard options and are discussed below in the section on processed data.

The analogue telemetry system used with this equipment has been introduced by the Operational Instrumentation Branch of the Meteorological Office as standard for general use. The system has a resolution of 0·1 per cent, and an accuracy not worse than $\pm 0{\cdot}2$ per cent over a wide temperature range. Chosen for reliability, it uses internationally agreed carrier frequencies, and encodes the data on to the carriers by frequency shift keying. The Mk 5 system uses two analogue channels to transmit continuous wind-speed and direction data, but the same modulation and demodulation units (modems) could be used for 50-baud digital transmission if required. The modems are approved by the Post Office for connection to public lines in the United Kingdom. On lines using repeater amplifiers the transmission distance is unlimited, otherwise the distance is limited to that which gives a transmission loss of about 46 decibels at the carrier frequency in use. Typically, this distance would be about 80 km. Figures 4 and 5 show typical arrangements of units to meet local and remote telemetered applications.

Telemetry is not essential to the basic operation of the Mk 5 system. It is only needed when displays are required at a great distance from the sensors, or when the route from the sensors to the displays precludes the economic installation of short lines. Without the telemetry option, the sensors can be linked by cable to the processing unit over distances up to about 3 km, and the processing unit can be linked by cable to the displays up to a distance of about 1 km (a loop resistance of about 100 ohms).

Information processing. The basic meteorological information produced by the sensor–transducer combinations is transmitted in an unprocessed state to the receiving points. In this form it contains all the information which the sensors are capable of providing, and is not degraded in any way. For many purposes, however, the data require to be processed in varying ways. The versatility of the Mk 5 system is such that it can present the data processed in different ways at different displays. Probably the most useful processing method used is that of time-averaging, to give displays of wind speeds averaged over various lengths of time (e.g. a 10-minute mean wind for meteorological reporting, or a two-minute running-mean wind for air traffic control use). Other facilities now available provide running means of wind direction. The circuits used for this purpose are capable of dealing with the discontinuities generated when the reset logic system of the direction encoder removes the scale deflexion from its

To face page 134

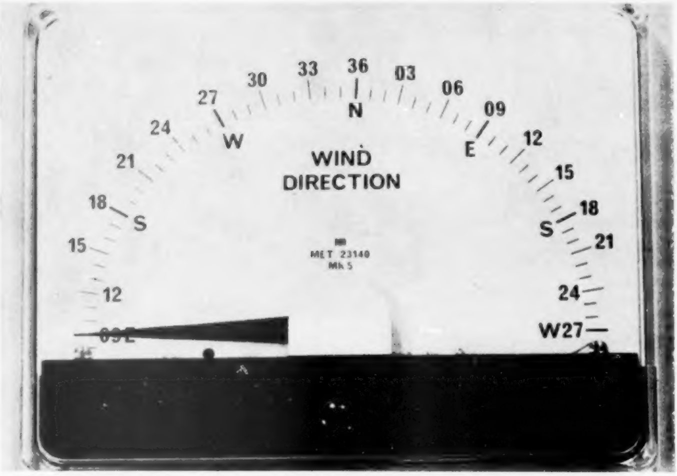

PLATE I — 180-DEGREE WIND-DIRECTION DIAL (NORMAL METER TYPE)
See page 130.

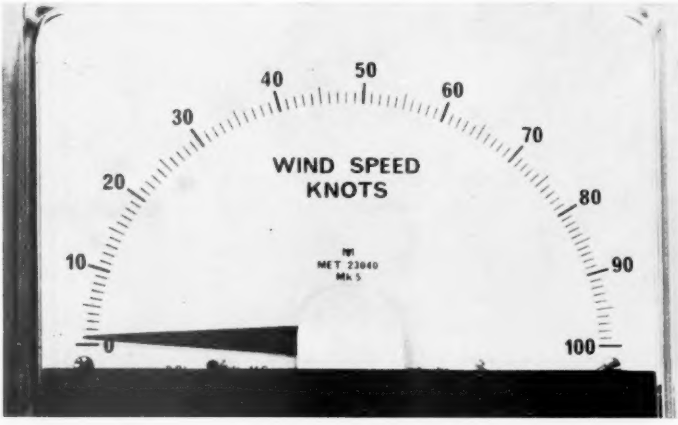

PLATE II — 180-DEGREE WIND-SPEED DIAL (NORMAL METER TYPE)

PLATE III — AIR TRAFFIC CONTROL 360-DEGREE COMPASS-TYPE WIND-DIRECTION DIAL

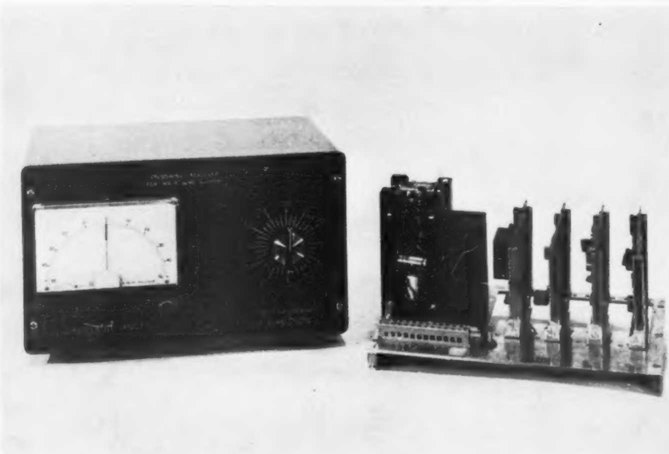

PLATE IV — MK 5 SYSTEM CROSS-WIND RESOLVER

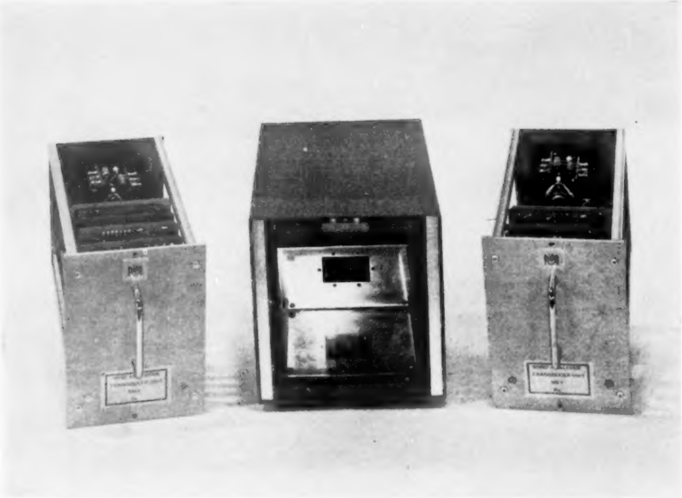

PLATE V — FREE-STANDING ENCODER AND DECODER UNITS, WITH CASE

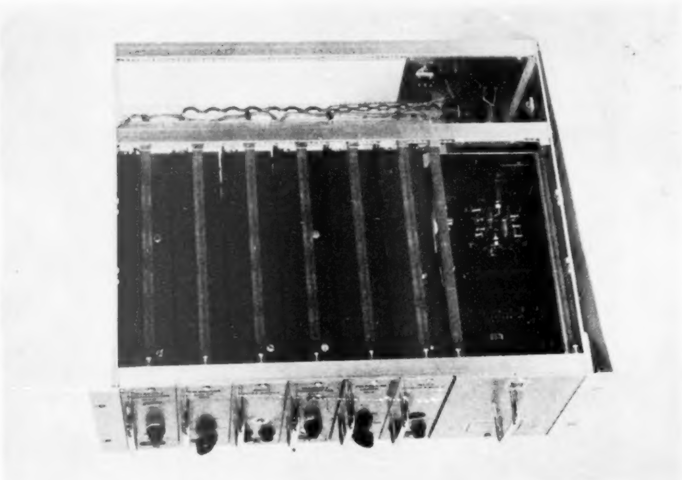

PLATE VI — TELEMETRY TRANSMITTER UNIT UNCASED, FOR 19-IN RACK MOUNTING

To face page 135

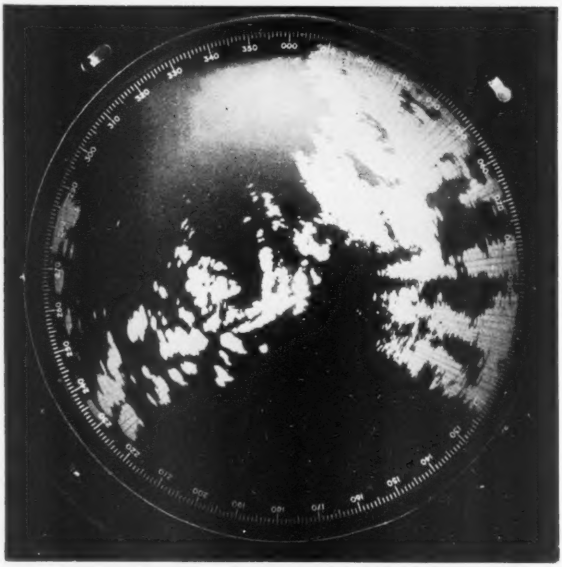

PLATE VII — GROUND CLUTTER OBSERVED BY TYPE 43S RADAR AT LLANDEGLA WHEN THE BEAM AXIS WAS AT AN ELEVATION OF 0·5°

See page 140. The outer range is 50 kilometres.

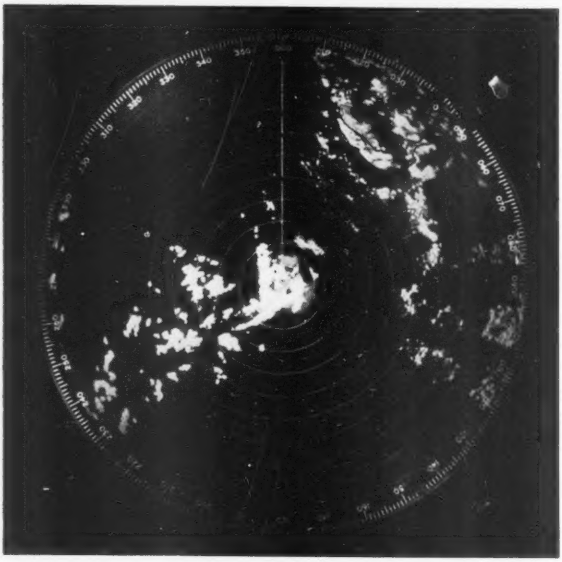

PLATE VIII — AS PLATE VII, EXCEPT THAT THE RADAR BEAM WIDTH HAS BEEN NARROWED

The coastline of North Wales and Lancashire is also shown.

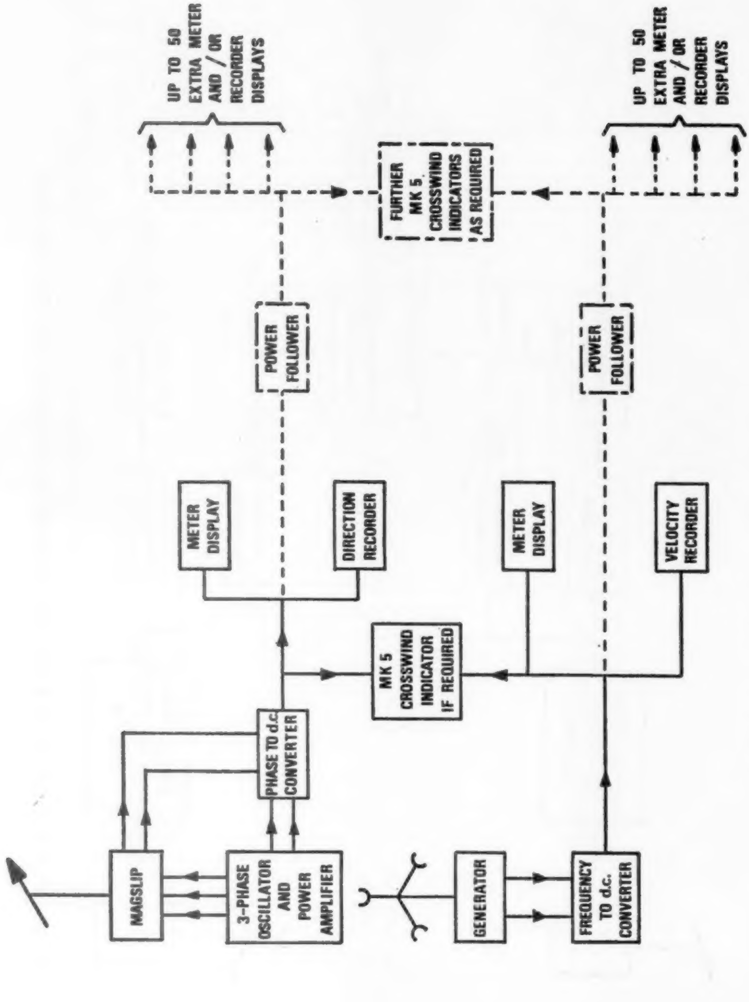

FIGURE 3 — BLOCK DIAGRAM OF BASIC LOCAL MK 5 WIND SYSTEM

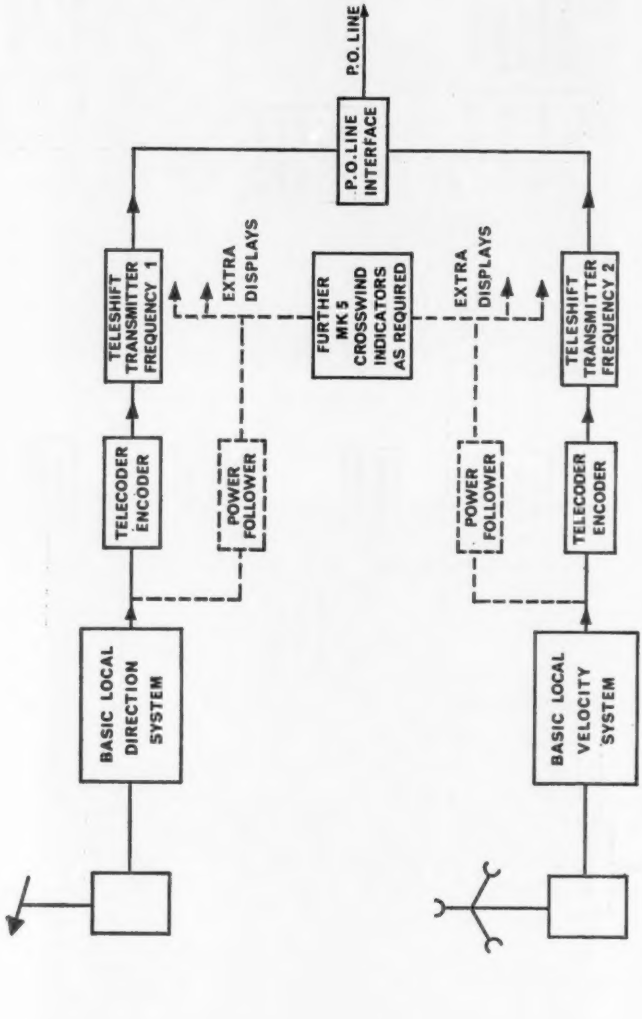

FIGURE 4 — BLOCK DIAGRAM OF BASIC TELEMETERED MK 5 SYSTEM (TRANSMITTER END)

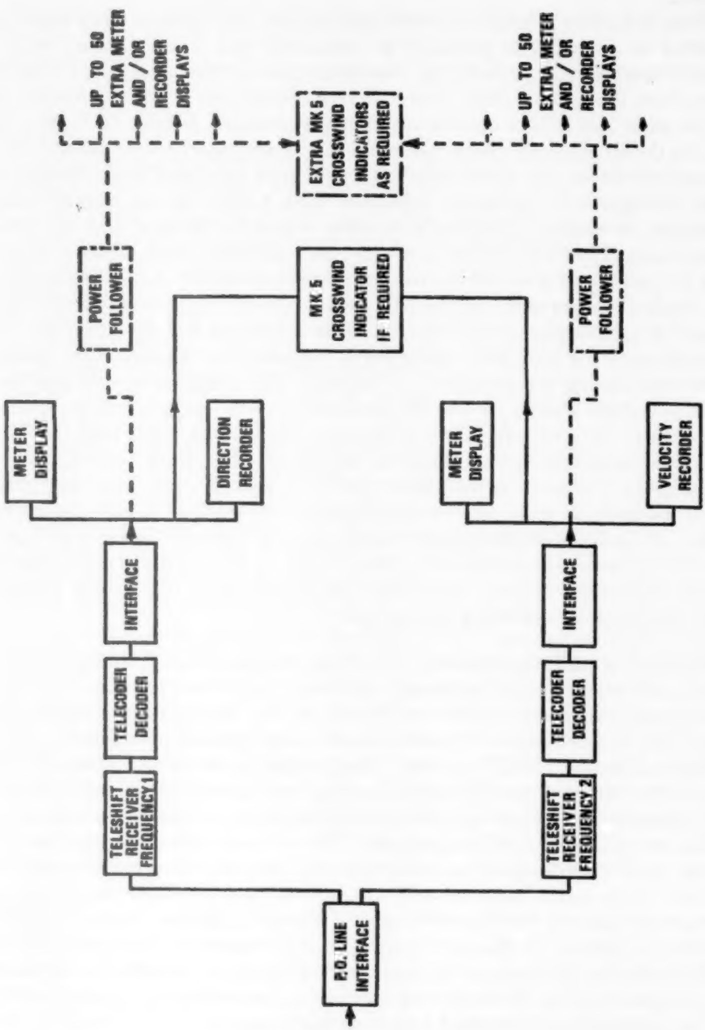

FIGURE 5 — BLOCK DIAGRAM OF BASIC TELEMETERED MK 5 SYSTEM (RECEIVER END)

extreme positions, and can generate their own independent scale switching when their outputs reach the scale extremes. These direction-averaging circuits are also capable of changing the 540-degree scale to a 360-degree scale and vice versa.

Facilities are also available to detect and indicate the value of the maximum gust, either in a fixed time period (e.g. maximum gust in each hour) or in a constantly moving time period (e.g. maximum gust in the previous 10 minutes counting from the present time), and to derive the number of times gusts exceed the mean wind speed by a certain value or percentage. Similar facilities (e.g. maximum deviation from mean) are available in relation to wind direction.

A requirement in any general-purpose system of this kind is the facility to produce orthogonal components, especially with respect to *any* selected axis; for example, to measure the winds blowing across or along a selected path. An instrument (Plate IV) to perform this task is already available as a part of the Mk 5 system, and is an all-electronic counterpart of the cross-wind resolver shortly coming into service with the Mk 4 wind system. The 10-volt linear scale representing 540 degrees in direction is first corrected for deviation of axes from north, and for magnetic deviation if required, by algebraically adding voltages representing the required corrections. The resultant is split into two compatible voltage scales of 0–360 degrees and 0–180 degrees, which are further separated into voltages representing 90-degree quadrants, each with a signal giving the appropriate sign (positive or negative). The linear voltage representing a given quadrant is then converted to a sine function and multiplied by the instantaneous value of the wind speed. The output, which represents the value of the required orthogonal component, is displayed on a centre-zero meter, the direction of deflexion being determined by the quadrant sign (positive or negative) derived earlier. The analogue output from this device is again available for further processing if required.

Construction and electronics. The basic constructional techniques which have been adopted as standard in all new instruments and systems developed in the Operational Instrumentation Branch of the Meteorological Office are based on the International Telephone and Telegraph Corporation Standard Equipment Practice (ISEP) system. Individual parts of the circuitry are broken down into conveniently sized packages and mounted on small plug-in cards. Assemblies of cards are mounted into larger modules (or sub-units) which in turn plug together in sub-racks. The sub-racks either fit together into complete 19-in rack assemblies, where the equipment is large and complex, or fit into 19-in instrument cases to provide a finished assembly when the equipment is relatively small and compact. Views of different types of finished assemblies are shown in Plates V and VI. This method of assembly allows rapid fault-finding and repair by exchange of cards or modules in the field, whilst also giving great flexibility for altering or extending the capability of a system by adding plug-in cards for various purposes.

To ease maintenance and spares stocking, the components used are chosen from a restricted list of approved parts for which military-quality alternatives are available. Because of careful screening of components used, and the constructional techniques employed, which include the duplication of connections to all circuit cards, the reliability of the equipment will be high. Some sets of the telemetry equipment have now been in use for more than two years without

any failures, and equipment sub-units have been run for more than a year without any failures. The various circuits have all been found to operate correctly throughout the temperature range $-20°$ to $+60°$ Celsius.

Conclusion. Design of the Mk 5 wind system commenced in 1969 and prototype development was completed in one year. Since then the system has been undergoing field trials, user-evaluation trials, and production engineering. As a result of trials using a specially made sensor in which a single wind vane drove both Mk 4 and Mk 5 transducers, carried out in conjunction with the Observational Requirements and Practices Branch of the Meteorological Office, it has been shown that the accuracy and performance of the Mk 5 system is at least equal to that of the Mk 4 system. In fact, in view of the known deficiencies of the Mk 4 system, it is likely that most of the small discrepancies between the two systems should be ascribed to errors in the older system.

The basic Mk 5 system is now available for production, and most of the ancillary facilities referred to in the text are approaching this stage. An example of this equipment is in routine operational use for relaying wind information from Beaufort Park to the main Headquarters Building in Bracknell, as part of the CARD (Continuous Automatic Remote Display) system.* This particular installation provides analogue chart records in the Central Forecasting Office, and digital displays in the main entrance hall some 350 m away.

The most important installation has recently been made at London/Heathrow Airport, where the number of displays required could no longer be supported by the existing Mk 4 system. This installation comprises three full sets of Mk 5 receiving equipment and two sets of transmitting equipment, interlinked in such a way that failure of any part of the equipment will not deprive the airport of wind information. As a further precaution, the various parts of the equipment are connected to the airport emergency power grid, and the sensors themselves are duplicated, as also are the Post Office lines used for the telemetry links from the processing unit to the displays.

Other installations are in the course of planning. Installation of a system at Stornoway Airport is about to start, and it is possible that the National Institute of Oceanographical Sciences will use one of these equipments on their research ship *Discovery*. Another set is being used by the Royal Armaments Research and Development Establishment at Fort Halstead, in conjunction with a digital data-logger, and the Royal Aircraft Establishments at Bedford and Aberporth are installing sets. A second CARD system is being used for the telemetry of wind data from the Post Office Tower to the London Weather Centre. Telemetry of other data will be added to this system shortly.

The Mk 5 wind system represents one of the first of the new generation of instruments now coming into service in the Meteorological Office. It is based on the newer technologies, using integrated circuits and digital techniques in addition to analogue processes. It is modular in concept, which allows systems to be expanded (or contracted) to meet the particular requirements of each installation. The construction allows maintenance and repair by replacement of individual cards or modules, and the general design philosophy is such that electronics failures should be reduced to a negligible level.

* SANDS, K. J. T. and WILKINSON, D.G.; The meteorological transmission system operating between Beaufort Park and Meteorological Office Headquarters. *Met Mag, London*, **103**, 1974, pp. 74–81.

Acknowledgements. Acknowledgement is made of the efforts of the team who have been engaged in this development, in particular Mr D. Painting, upon whose original work the wind-direction processing circuits are based, and Mr D. G. Wilkinson, who was responsible for the production engineering of the system.

551.501.8: 551.577

GROUND CLUTTER OBSERVED IN THE DEE WEATHER RADAR PROJECT

By T. W. HARROLD

Anyone who has viewed a weather-radar display is aware that echo from precipitation is difficult to detect in some localities because echo from the ground, buildings, trees etc., termed ground clutter or permanent echo, is also present. This clutter can be reduced by elevating the radar beam so that less energy strikes the ground, but then the precipitation in the beam may not be representative of that reaching the ground. At long ranges the beam may even be above the precipitation. In making quantitative estimates of the precipitation at the surface it is particularly important that the beam should be set at as low an angle as possible, which is usually about 0·5°, and ground clutter cannot be completely avoided. It can be minimized by careful siting of the radar and by using a narrow radar beam.

In the Dee Weather Radar Project[1] a standard Plessey Type 43S weather radar at Llandegla was used to measure the rain falling on to sub-catchments of the River Dee. This radar has a beam width to half-power points of 2°. Plate VII shows the extent of ground clutter observed. Over the Dee Valley, to the south-west of the radar, the echo was broken, and it was found possible to extrapolate rainfall estimates across individual echoes, but to the north-east the echo was continuous and rainfall measurements were not possible. The conventional definition of beam width means that half of the total energy radiated is within a 2-degree cone. However, when considering the extent of ground clutter it is necessary to consider also the energy outside the cone. For instance, north-east of the radar the land is at an elevation of about $-1°$, or 1·5° off the beam axis, and therefore outside the half-power points. The incident radiation was about 10 dB (a factor of 10) below that at the beam axis but this was sufficient to result in the echo shown. A further problem with the 43S radar was that the melting layer (bright band) was frequently within the beam in winter, which lessened the accuracy of the estimates of surface rainfall.

Because of these difficulties the beam width as defined by the half-power points has been reduced to 1°. This has been accomplished by changing the radar wavelength from S-band (10 cm) to C-band (5·6 cm) whilst retaining the same aerial (the alternative of increasing the aerial size would have been much more costly). When the beam axis is at an elevation of 0·5° the melting layer is now intersected within a range of 50 km when it is less than 1350 m above sea level instead of 1800 m. The ground clutter now observed is shown in Plate VIII. The overall sensitivity of the radar is very similar to that of the 43S, and the reduction in clutter compared with Plate VII has been obtained by narrowing the beam and also by improving the profile of the lower portion

of the beam. The power density 1·5° below the beam axis is about 30 dB (a thousandfold) less than at the beam axis. Measurements of surface rainfall are now possible north-east of the radar.

During the latter part of 1974 the radar is to be converted into a real-time system, centred around a Digital Equipment Corporation PDP 11-40 minicomputer, using software being developed by a team at the Royal Radar Establishment.[2] This software includes provision for the extrapolation of rain echo into a region of ground clutter so that the display available to any user of the data will be free of this clutter.

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2. TAYLOR, B. C.; The development of a prototype system for the processing, transmission and remote display of data from a weather radar. Malvern, Royal Radar Establishment, 1974. (Unpublished, copy available in the Meteorological Office Library, Bracknell, Berks.)

551.551.2:634.0

WIND-SPEED MODIFICATION BY A VERY ROUGH SURFACE

By H. R. OLIVER

(Institute of Hydrology, Wallingford)

Summary. Wind speeds were measured over Thetford Chase with a standard anemograph and sensitive anemometers on three very windy days. It is shown to be possible to obtain from the anemograph traces values for average speeds and maximum gusts reduced to the standard meteorological height of 10 m above the 'surface'.

Data for Thetford were compared with results for Meteorological Office stations in or near the East Anglia region. It was found that the hourly average speeds measured over the forest were only about 60 per cent of those measured at the nearby stations. The reduction in gust magnitudes — of obvious importance to forest damage problems — was not so large. The gust/mean ratio for the forest was found to be about 2·0 — a value typical of urban areas — in comparison with an average value of less than 1·6 for the other stations.

It is possible to estimate winds above a forest from measurements made elsewhere so long as the calibration constant between the sites can be measured or estimated.

Introduction. The Institute of Hydrology is carrying out an extensive research project, the object of which is to investigate the meteorological factors concerned with the evaporation process from a forest. The site is in Thetford Chase, which is a large fairly flat area mainly planted with a mixture of Scots and Corsican pine. The trees within half a kilometre of the site are all Scots pine with a mean height of about 16½ m.

On 2 April 1973 a severe gale occurred and some damage to the forest resulted. The equipment was operated during the gale to obtain wind-profile data; sensitive Casella anemometers were mounted at 11 levels within and above the canopy and there was also an anemograph trace of the output from a standard Meteorological Office cup generator anemometer Mk 4. A paper describing the micrometeorological and forestry results is being published (Oliver and Mayhead[1]) but of particular interest here is a comparison of results obtained over Thetford Chase with anemograph data from elsewhere in East Anglia. Two further days with strong but less severe winds which have occurred whilst the full equipment was being operated have also been investigated.

Data on the effects of gales upon forested and other areas have obvious relevance to several planning problems. It is also useful to be able to estimate wind speeds above a forest by using only measurements made elsewhere.

Theoretical considerations

(a) *Effect of surface roughness on wind-profile shapes.* The wind profile above a surface can be expressed in the standard logarithmic form

$$u = \frac{u_*}{k} \ln \left(\frac{z}{z_0}\right), \qquad \ldots (1)$$

where u_* is the friction velocity, k is von Kármán's constant and z_0 is the roughness length. This equation can be used for any surface provided that the height z is that above the zero-plane displacement, d,† rather than above the ground surface. For short vegetation such as grass the effect of d can safely be neglected; for taller vegetation a value of d of 75 per cent of crop height may be used in the absence of actual data. The simple logarithmic equation applies for neutral conditions. For the strong-wind conditions on the days under investigation here the stability was indeed near-neutral. The Richardson number (the most commonly used stability function), which is expressed as

$$Ri = \frac{g}{T} \frac{\partial\theta/\partial z}{(\partial u/\partial z)^2},$$

tends to zero for high wind speeds because the denominator contains the square of the wind-speed gradient.

For two surfaces with roughness lengths $z_{0,1}$ and $z_{0,2}$ the relationship between the speeds measured at heights z_1 and z_2 above the crop zero-plane displacements can be shown to be given by the relation:

$$u_1 = u_2 \left(\frac{\ln (z_1/z_{0,1})}{\ln (z_2/z_{0,2})}\right). \qquad \ldots (2)$$

This equation shows that it is only at very great distances above the surface that the effect of roughness length becomes negligible and the profiles merge (see Figure 1).

Hence the mean wind speed measured at a certain height above d for a rough surface (large z_0) will be considerably *less* than the mean speed measured at the same height above a grass surface (small z_0, negligible d); from purely theoretical considerations the overall severity of a gale will therefore be reduced at levels close to a surface with a large roughness length, be it a forest or city.

(b) *Effect of surface roughness on gust sizes.* The previous discussion applies to *mean* wind speeds and profiles — certainly not to those obtained by averaging over periods shorter than five minutes. Detailed analyses of anemograph records have shown that gust strengths are not so much reduced by surface roughness effect (Shellard[2]). It is a consequence of this that the ratio of maximum gust to mean wind speed must increase with surface roughness. There is considerable variation in this ratio between various gale events but it has been suggested (Hardman *et alii*[3]) that gust/mean-wind ratios can be taken as 1·5, 1·7, 1·9 and 2·1, corresponding to the four terrain classes ranging from open level unobstructed country to very rough surfaces such as cities.

Analysis of results. The wind-speed data obtained at Thetford on 2 April 1973 were by far the highest speeds that had occurred while detailed measurements were being made. The maximum gusts recorded by the anemograph were also the highest that had ever been obtained in the five years during which

† If the simple logarithmic profile is extrapolated into a crop canopy the wind speed reduces to zero at a height of $(d+z_0)$ above the ground surface.

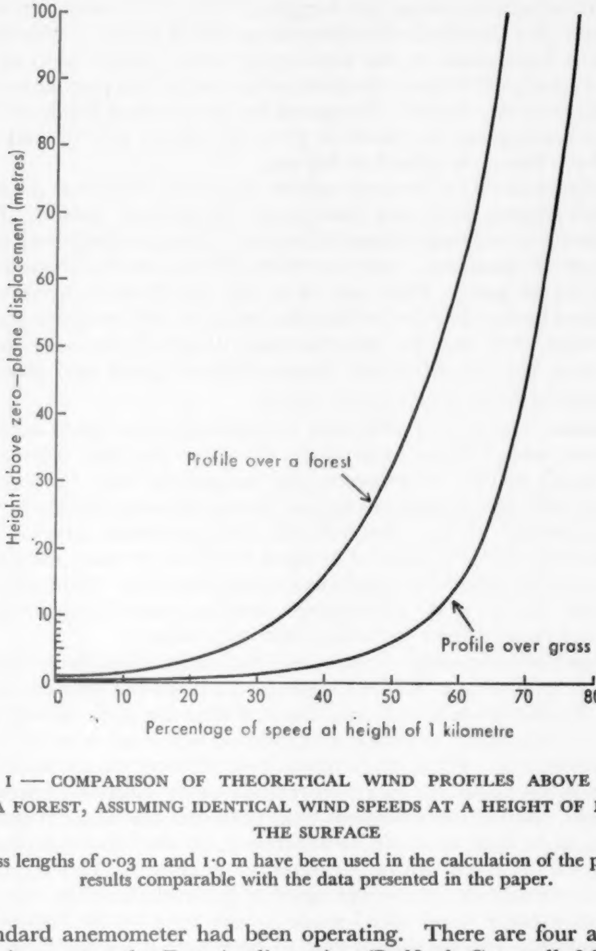

FIGURE 1 — COMPARISON OF THEORETICAL WIND PROFILES ABOVE GRASS AND ABOVE A FOREST, ASSUMING IDENTICAL WIND SPEEDS AT A HEIGHT OF 1 km ABOVE THE SURFACE

Roughness lengths of 0·03 m and 1·0 m have been used in the calculation of the profiles to give results comparable with the data presented in the paper.

the standard anemometer had been operating. There are four anemograph stations in or near the East Anglia region (Bedford, Cranwell, Marham and Coltishall) for which gale return-period analyses have been carried out and for which data are still being recorded (Hardman *et alii*[3]). The measurements obtained at these stations suggest that the general level of the gale in East Anglia had a return period approaching 10 years. The gale was so severe that many of the sensitive polystyrene anemometer rotors used in the measurement of wind profiles were damaged. However, whilst the rotors were still intact during the early part of the gale, analysis has verified that the wind profile above the forest did indeed follow a pure logarithmic form with a roughness length of about 1 m and a zero-plane displacement of 12 m. Analysis of the profiles obtained on the other occasions produced similar results which are in agreement with those found for more normal wind-speed conditions (Oliver[4]).

The standard height for anemograph data is 10 m above the 'surface'; for

a rough surface such as a forest this is equivalent to 10 m above the zero-plane displacement. For Thetford, therefore, the standard height is 22 m above the ground. The wind speeds at the anemograph sensor height of 31 m and the shape of the wind profile above the forest being known, it is possible to calculate the speed at any other height. The speeds for the standard height of 22 m are obtained by multiplying the speeds at 31 m by a factor of 0·79, and the data presented have been determined in this way.

The results obtained at Thetford and the published data from the Meteorological Office stations in or near East Anglia are given in Table I. It can be seen that there is a very large reduction in hourly average wind speeds measured over the forest in comparison with the other stations but that the reduction in gust size is not so great. There are of course considerable variations in the absolute values obtained at the various sites owing to their geographical separation. For some of the sites the effective sensor height is also not equal to the standard 10 m but the differences between these speeds and those at the standard height will not exceed 5 per cent.

Discussion. The very considerable reduction in wind speed over a forest in comparison with measurements made elsewhere has been clearly demonstrated; a much smaller reduction in gust magnitudes has also been shown. These results are of importance to anyone concerned with forestry or with the erection of structures within a forested area. The gust/mean ratio for Thetford Chase constantly takes the value of about 2, which is the same ratio as would be expected for an urban area with many large buildings (Hardman *et alii*[3]). The gust/mean ratios for the anemograph stations mostly lie within the range 1·5–1·7, which is what one expects for fairly open country.

The problem of forecasting or estimating maximum mean speeds for a given area of rough terrain from wind data obtained outside the area can be solved if wind-speed measurements are available covering the same period for both areas. It is then possible to obtain a calibration factor between the measurements at the two sites. For average speeds over Thetford Chase this factor has been shown to be about 1·6 or 1·7 in relation to the nearest Meteorological Office stations. Actual measurements from both sites also make it possible for equation (2) to be used to obtain an effective z_0 for the Meteorological Office station if z_0 for the forest can be measured or estimated. This equation can then be used to calculate the average speed at *any* level above the canopy from one value of average wind speed made at *any* level at the meteorological observing station. The maximum gust to be expected for any gale event is equal to about twice the calculated hourly average speed.

Acknowledgement. This paper is published by permission of the Director, Institute of Hydrology.

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TABLE I —ANEMOGRAPH DATA FOR THREE DAYS WITH STRONG WINDS

Anemograph site	Effective height	Maximum hourly wind speed			Ratio to value for Thetford			Maximum gust			Ratio to value for Thetford			Ratio of gust to hourly average		
	metres	*m/s*						*m/s*								
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
THETFORD	10	11	9	7½				22	19	15				2·0	2·1	2·0
Cranwell	13	19	16½	13½	1·7	1·8	1·8	28	25	21	1·3	1·3	1·4	1·5	1·5	1·6
Wittering	10	14½		10½	1·3		1·4	24½		14½	1·1		1·0	1·7		1·4
Bedford	9	20½		11½	1·9		1·5	34		18	1·5		1·2	1·7		1·6
Stansted	10	14½			1·3			26			1·2			1·8		
Wattisham	10	21½	15½	10½	2·0	1·7	1·4	32½	22	15½	1·5	1·2	1·0	1·5	1·4	1·5
Honington	13	18		11	1·6			29		17	1·3		1·1	1·6		1·5
Coltishall	10	19	13	11	1·7	1·4	1·5	32½	20½	17	1·5	1·1	1·1	1·7	1·6	1·5
West Raynham	14	19½	16½		1·8	1·8	1·5	34	24		1·5	1·5		1·7	1·5	
Marham	10	19	14	12½	1·7	1·6	1·7	29½	22	18½	1·3	1·2	1·2	1·6	1·6	1·5

1 = 2 April 1973 2 = 26 May 1972 3 = 28 August 1971.

Data for Cranwell–Marham inclusive extracted from appropriate issues of the *Monthly Weather Report*, HMSO, London.

551.515.527:551.577.21(213)

THE MAGNITUDE OF HORIZONTAL DIVERGENCE AND VERTICAL MOTION ASSOCIATED WITH UPPER TROPOSPHERIC DISTURBANCES OF THE EQUATORIAL ATMOSPHERE

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Summary. It is shown that the changes of contour pattern from Duct to Bridge and from Duct to Drift in the upper troposphere can raise the top of the moist layer of the equatorial atmosphere by 150–200 mb over a period of three to four days, with important effects on the weather.

Introduction. It has been explained* how horizontal divergence can occur in the upper troposphere near and at the Equator when the contour pattern is changing from Duct to Bridge or from Duct to Drift. It remains to assess the magnitude of the divergence and the associated vertical motion.

Change from Duct to Bridge. If $\mathbf{V}_{ag}$ is the ageostrophic wind,

$$\mathbf{V}_{ag} = \mathbf{k} \times \frac{1}{f}\frac{d\mathbf{V}}{dt},$$

where $\mathbf{V}$ is the horizontal wind, f the Coriolis parameter and $\mathbf{k}$ unit vertical vector.

Hence during the gradual change from Duct to Bridge, if parcels of air at latitudes 5°N and 5°S are experiencing an acceleration towards east of magnitude 5 m/s per day, which is by no means improbable at 300 and 200 mb, the magnitude of $\mathbf{V}_{ag}$ is found from the above equation to be 4·6 m/s. The direction of $\mathbf{V}_{ag}$ is towards north in the northern hemisphere, and towards south in the southern hemisphere, and the resulting mean horizontal divergence between 5°N and 5°S is $0{\cdot}8 \times 10^{-5}\ s^{-1}$.

Typically the change from Duct to Bridge affects only the upper one-third of the troposphere by mass (400–100 mb). Hence if there is simple tropospheric compensation and a mean upper divergence of $0{\cdot}4 \times 10^{-5}\ s^{-1}$ is assumed, this would be balanced by mean convergence of $0{\cdot}2 \times 10^{-5}\ s^{-1}$ up to 400 mb. It follows from the equation of continuity that ω $(= dp/dt)$ at 400 mb is $-(1{\cdot}2 \times 10^{-3})$mb/s, or 2 cm/s.

This rate of upward motion is small compared with that associated with deepening lows of middle latitudes, but the change from Duct to Bridge is usually a slow process lasting three or four days. Taking a mean value of ω in the lower troposphere as $-(0{\cdot}6 \times 10^{-3})$mb/s, upward motion would amount to 50 mb a day, so that the total decrease of pressure following the motion during the change of contour pattern would be 150–200 mb. This would raise the upper level of the moist layer, which characteristically is between 750 and 700 mb in the equatorial trough, to 550 mb, and the depth of the moist layer would be doubled from 2·5 to 5 km.

A useful forecasting guide well known to meteorologists practising in East Africa is to expect thunderstorms when the top of the moist layer reaches beyond the 0°C level, which is almost invariably between 600 and 550 mb.

* LUMB, F. E.; Upper tropospheric disturbances of the equatorial atmosphere and their influence on rainfall near the equator. *Met Mag, London*, **102**, 1973, pp. 269–272.

The above calculations show that the upper divergence associated with the change from Duct to Bridge over a period of three to four days is sufficient to raise the top of the moist layer above the 0°C level.

Change from Duct to Drift. Divergence caused by transequatorial flow accelerating down the pressure gradient is given essentially by $\partial V/\partial s$, the change of wind speed per unit distance along the streamline. An increase of speed by 5 m/s over a distance measured along the streamline equivalent to 5° of latitude is not exceptional at 300 and 200 mb. This corresponds to a horizontal divergence of $0{\cdot}9 \times 10^{-5}\ \mathrm{s}^{-1}$, which is nearly the same as that calculated above for the change from Duct to Bridge. Hence similar changes in the depth of the moist layer and in the weather can be expected, if the Drift pattern develops and persists over a period of three to four days.

Changes from Bridge or Drift back to Duct. For the reverse changes, upper convergence replaces upper divergence, with consequent marked reduction of rainfall, both in extent and in amount per unit area, within a period of 24–48 hours.

INSTITUTE OF PHYSICS AWARDS TO THE DIRECTOR-GENERAL

Dr B. J. Mason, C.B., F.R.S., Director-General of the Meteorological Office, has been awarded the Glazebrook Medal and Prize by the Institute of Physics 'for his contributions to numerical methods of weather forecasting by computer and for his success in encouraging the scientific spirit within the Meteorological Office'.

The Medal and Prize were awarded at the Annual Dinner of the Institute on 7 May 1974.

NOTES AND NEWS

METEOROLOGICAL OFFICE WEATHER OBSERVING SYSTEMS

Ten Meteorological Office Weather Observing Systems (MOWOS) Mk 2 have been obtained for operational evaluation. Three have been installed at Beaufort Park, South Farnborough and Leuchars, and six more are to be installed at Pershore, Filton, Ross-on-Wye, Anvil Green, Bingley Moor and Holme Moss by the autumn of 1974.

MOWOS Mk 2 is an interrogable system which uses the public switched telephone system. It provides mean wind speed and direction, atmospheric pressure, dry-bulb, wet-bulb and dew-point temperatures, duration of bright sunshine, rate of rainfall and cumulative rainfall. Spare channels are available for other data. The data are updated every five minutes.

The system has attracted the attention of several overseas governments and was exhibited at the meeting of the World Meteorological Organization Commission for Basic Systems held in Belgrade from 18 March to 5 April 1974.

THE MEASUREMENT OF RAINFALL BY RADAR

On 13 December 1973 a colloquium on the Quantitative Measurement of Areal Rainfall by Radar was held at the Meteorological Office College, Shinfield Park. It was organized jointly by the Water Resources Board and the Meteorological Office and was attended by about 60 invited delegates, mostly from the water industry. Results from the Dee Weather Radar Project were discussed and a report entitled 'The Use of a Radar Network for the Measurement and Quantitative Forecasting of Precipitation' was distributed. This report, which was written by staff of the Water Resources Board, the Meteorological Office, Plessey Radar Limited and the Greater London Council, assesses the potential benefits and costing of a network of weather radars in the United Kingdom. The possible locations of these radars and potential users of the resultant data are also discussed.

One of the problems in the accurate measurement of surface rainfall by radar occurs when the radar beam intercepts the melting layer. In order to minimize this effect, the beam width of the radar used in the Dee Weather Radar Project has recently been reduced from 2° to 1°. This has been achieved by changing the operating wavelength from S-band (10 cm) to C-band (5·6 cm).

NUMERICAL MODELS FOR LONGER-RANGE FORECASTING AND CLIMATE SIMULATION

The development of mathematical models for longer-range forecasting and simulation of climate continued at a high level. A complete version of the 11-layer model is now available, and the first of a series of 14-day prediction experiments planned for this year has been started. Results previously obtained from a 6-day mean of the model, which at that stage, however, did not include physical representation of the effects of radiation, were encouraging. Much work has also been done on the tropical model for use with the data due to be available from the GARP Tropical Experiment in the summer of 1974.

RADIOSONDE ASCENTS FROM MERCHANT SHIPS

The last voyage, in a six-year programme of radiosonde ascents made from merchant ships as a contribution to the World Weather Watch scheme, was completed in December 1973. The help willingly given to the meteorologist who sailed in each vessel by officers and crew members of the Sugar Line Company contributed significantly to the good results obtained. Communication delays in remote tropical regions and the lack of upper-wind observations prevented full benefit being gained from the efforts of those concerned. However, the programme provided 1437 soundings to a mean altitude of 21 km in regions not otherwise subject to radiosonde surveillance, thereby giving much useful information — especially for climatological purposes.

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NOTICES

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